brown. In life the iris is pale yellowish brown dotted finely and densely with dark golden-brown exeept for a narrow yellowish or whitish margin surrounding the "straight vertical" pupil.

The dorsal ground colour of *taeniata* varies from pale reddish brown to pale grey (sometimes almost white). The dorsal stripes vary from orange to pale yellow; the lateral stripes are grey; and along the venter is a broad zone of grey enclosing a yellow or orange stripe.

DISCUSSION

While there ean oe no question that *michaelseni* and *taeniata* belong to different taxa, it is less certain whether they are specifieally distinct or merely raees of one species.

At present their known ranges are separated by a gap of 350 miles. i.e. fom Denham north-east to Turee Creek. This gap is not large eompared to the 1,060 miles that separate Turee Creek from Elliott, over which *taeniata* undergoes seareely any variation. Nor is the gap large in view of the striking differences between the two taxa; for if intergradation did oeeur, eharaeter gradients would neeessarily be very steep in the intervening region.

We therefore reeommend that the two geckos be provisionally treated as full speeies: *Diplodactylus michaelseni* Werner and *Diplodactylus taeniatus* (Lonnberg & Anderson).

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OBSERVATIONS BY THE LATE F. ALDRICH ON AUSTRALIAN MARINE CRAYFISH IN CAPTIVITY

Edited by R. G. CHITTLEBOROUGH

I. INTRODUCTION

The late Frederick Aldrich* was born on August 15, 1873, in New South Wales. He was appointed as a Fisheries Inspector in that State on March 19, 1900, and from 1905 to 1911 held the position of Keeper of the Gunnamatta Hatchery at Port Haeking, New South Wales. This fish hatchery was designed and constructed by H. C. Dannevig for the mass hatehing of fry of marine fish, especially flounder (Lockyer, 1915).

During the period from 1905 to 1911, F. Aldrich maintained speeimens of the local crayfish *Jasus verreauxi* (Milne-Edwards) at the hatchery, recording observations on growth, spawning and larvae. The results were not published and this species has been studied very little in the 55 years sinee this pioneering work.

* Biography in "The Cyclopedia of W.A.," ed. J. S. Battye, vol. 1, 1912: 513-514 (with portrait); Dept. Fisheries and Fauna, W.A. Monthly Service Bull., 14 (8), Oct. 1965: 171.

In 1911, Aldrich moved to Perth as Chief Inspector of Fisheries in Western Australia, remaining in this position until his retirement in 1938. During this period he made similar observations upon the western crayfish, *Panulirus cygnus* George (then known as *P. penicillatus)*. These results were not published, nor were they known to research workers studying this species subsequently.

Aldrich died in Perth, Western Australia, on September 21, 1965. Amongst his papers, his family found a lengthy account of Australian marine crayfish including distribution and life history as well as an account of the fisheries and their economic potential, as known more than thirty years ago. Although much of the material is now out of date or has been reviewed independently by later authors, the experimental work upon living crayfish held in tanks and crates, begun by Aldrich over sixty years ago, yielded valuable information, some of which has not been duplicated by those who have studied these species subsequently.

Bearing in mind the state of knowledge on fisheries problems at that time, the soundness of this man's approach to fisheries management has generally been overlooked. With our renewed interest in the ecology of Australian crayfish (involving aquarium studies under controlled environmental conditions), the discovery of this general account of F. Aldrich's original observations is very timely. The results of his experimental work have been extracted from his notes and assembled for publication. Unfortunately the notes give little detail of the conditions under which the crayfish were held or of techniques used. In some instances the notes did not specify whether a particular observation referred to *Jasus verreauxi* or to *Panulirus cygnus:* we can only assume that both species behaved similarly in these instances.

Aldrich's notes are given verbatim in the following sections, the portions within square brackets being my annotations. The final section (Conclusions, on p. 7 is mine, with Aldrich's note within quotation marks.

II. MOULTING

The very young animals moult at frequent intervals, perhaps eight or ten times annually, the moulting frequency decreasing until the age of reproductiveness. As the different age classes become distributed over suitable areas of ocean floor so individuals showing signs of a recent moulting are taken during different months of the year.

Adults moult once annually; it is believed that a cessation of growth foretells death. The moulting of adults is confined to a particular period and one of relatively short duration. Numbers of marine crayfishes in captivity provide material for observation. It is, in all probability, necessary to make allowances for the changed conditions but whatever effect this departure from the usual may have upon the animals concerned, a well defined moulting period has been observed in adults of both sexes of *J. verreauxi.* During three successive years known individuals moulted during June, while a greater number moulted during July. None moulted earlier than June. In no one instance did an adult of either sex moult more frequently than once during the year—the majority moulted during the identical months of three successive years. Younger (sexually immature) animals with a total body length of between 9 and 10 inches, moulted twice during the year, during February and again during August.

Marine crayfishes preparing to moult can be distinguished from their fellows by their movements and by their generally dull appearance. It is not uncommon to find the upper surface of the carapace marked with coral-like growths or with seaweeds,

stalked diatoms or other marine growths. In general, these growths are more abundant upon adults than upon the younger animals.

Prior to moulting a period of uneasiness is observed. The animals about to exuviate partake of little, if any, food. Periods of quiescence are followed by movements from one spot to another, the objective evidently being a suitable hiding place. At intervals, movements of the legs are observed, these movements suggesting a rubbing action over the eyes and the anterior portion of the carapace. [Similar behaviour was noted by Thomas (1966) observing the moulting of *P. cygnus*.]

An uninterrupted view of the act of moulting is rarely obtained. Over 300 moultings were recorded during a space of four years, yet in one instance only was the complete act performed during the hours of daylight. In numerous instances the carapace had become disarticulated at the pleon, indicating the act of moulting, but it had not been completed at nightfall.

Although incomplete in detail, the observations here recorded may be summed up as having consisted of two complete movements. The moulting animal assumed an upright position with the legs extended, the foremost pairs in a forward direction, the rearmost in a generally backward direction, the whole attitude suggesting a desire to secure a firm grip on the floor of the enclosure.

Following the disarticulation of the connection membrane the posterior margin of the carapace commenced to rise, but without any violent movements on the part of the animal. The elevation of the old carapace continued until, with some waving movements of the antennae and with a more or less backward movement or lunge, the whole of the "head" portion was freed of the old covering. A few rapid movements served to release the pleon, or tail portion, from the old shell. The newly moulted animal remained near the cast shell for a few minutes and then moved to another portion of the enclosure.

Newly moulted marine crayfishes have a sleek and fresh appearance. The new shell is soft to the touch but the smaller spines of the carapace retain some of their firmness. The larger spines may be easily bent or broken. No evidence of cannibalism has been observed. The newly moulted animals soon associated with their hard-shelled fellows. [In recent studies when P. *cygnus* were held in aquaria for a year or longer, there was a tendency to increasing cannibalism (of newly moulted crayfish) with time, possibly due to some dietary deficiency. Though details of feeding were not given, Aldrich does not appear to have experienced this difficulty.]

If permitted to remain in the water the discarded shells soon disintegrate, but if removed, dried and carefully stored they may be retained in a perfect condition for years. Twenty-four hours after moulting there is little appreciable difference in the firmness of the new shell, but forty-eight hours after the old shell has been discarded, the new covering becomes much firmer to the touch. The actual time required to complete the hardening process is affected by changes of temperature or, in the individual, by the amount of a particular food consumed. In from eight to twelve days after moulting the shell is quite firm. [Juvenile *P. cygnus* held in aquaria have been observed to commence feeding four days after moulting.]

If an appendage is lost several months before moulting, the regenerated limb, although not of normal proportions, is much more perfect than in the case of one lost but a few days before moulting. A recently lost appendage is usually reproduced in the form of a small papilla.

In the adolescents the regenerated appendages, although not of normal proportions, are much nearer perfection than those produced in the adults. In adults, three, sometimes four, moultings occur before the part is restored to its normal condition.

III. GROWTH

The rate of growth depends upon the frequency of exuviation and since the young animals moult more frequently than the adults, the rate of increased body length is greater in the young than in the old.

In the case of the very young animals the actual length increase after each moulting is small but as the animals increase in age and the moultings become less frequent, a pronounced increase in body weight and the length is recorded.

When the moultings are reduced to two during the year, a greatly increased body length and corresponding increase in weight is noted. These [annual] increases have been recorded as from 35 to 40 millimetres in length and approximately 5 ounces in weight. It is believed that at this period of the animal's existence, maximum increased body length and weight is recorded during any one year.

Of marine crayfishes in captivity a greater increased length of carapace measurement has been recorded in the males, although the total annual growth was much the same in males and females. Very large adults in captivity showed little growth. One very large male showed no growth whatever after moulting. [This was apparently a male *J. verreauxi* weighing 12lb. 4oz., held in captivity by F. Aldrich for more than four years.]

One of the difficulties experienced in observing the behaviour [and growth] of marine crayfishes in captivity is that of establishing identity of each when numbers are concerned. Several methods, including tagging, were tried but, for one reason or other they proved unsatisfactory. Critical examination disclosed the fact that all the spines, tubercles or other prominent features peculiar to the discarded shell were reproduced in the new. As in no two animals examined were all the smaller spines of the carapace or all the tubercles of the pleon similarly distributed, the old or cast off shells were marked or numbered, dried and preserved. At any subsequent period, the original occupant of any discarded shell could be located with very little difficulty.

IV. SPAWNING AND INCUBATION

The ovaries of *J. verreauxi* before spawning has commenced, appear as a bright red bilobed organ extending from the region of the head to the vicinity of the first segment of the abdomen. The eggs are tightly packed in the ovaries and this perhaps accounts for the fact that they are not quite spherical when newly spawned. After external attachment the eggs appear quite uniform in size and shape, but as the embryo develops a slight increase in size is apparent. Immediately prior to the release of the embryos they measure approximately 0.7 mm. in diameter.

The behaviour of the adult females in captivity indicates that, in the ocean, spawning occurs at night. During the course of observations extending over a period of four years, only one captive female was observed spawning during daylight hours. Numerous "berried females" were located from time to time but the spawning act had been unobserved. The position chosen by the spawning animal was in deep shadow.

The attitude of the spawning female differed from that which is normally assumed during rest. The whole of the head portion

was elevated; the second, third and fourth pair of legs were extended and were, apparently, employed for the purpose of securing and retaining a firm grasp of the wall of the enclosure. The abdomen was flexed, the uropods with the tail fan, forming a pocket or pouch for the reception of the eggs. At intervals there were somewhat rapid movements of the exopodites of the pleopods and occasionally the fifth pair of legs was brought into action.

The eggs flowed from the oviducts in a steady downward stream. The movements of the exopodites were repeated and it is believed were directed towards a more even distribution of the eggs. Spawning was completed in less than an hour.

The eggs as they left the oviducts may be best described as of a pale pink colour but soon after external attachment they darkened to a bright red. During the spawning process they are covered or smeared with a peculiar viscid matter which may be drawn out into a thread or stalk. Placed together in a receptacle, the eggs momentarily eling to one another.

Small fishes were observed in the vicinity of the spawning animal and they were obviously ready to consume any available eggs.

The number of eggs carried externally by the female marine crayfish appears to vary with the age or size of the animal concerned. Those of a relatively small female at its first spawning were measured at approximately 350,000; those of a larger and older animal measured approximately 650,000. In all probability the number carried by any large adult female does not exceed 700,000. [These egg counts are higher (especially at first spawning) than those recorded by Hickman (1945) and Bradstoek (1950) for *J. lalandii*.]

Microscopically, the very early stages of development—to that of eight cells—have been observed but the subsequent stages were not followed because the eggs soon die if removed from the parent animal.

"Berried females" if carelessly handled during removal from one place to another, may destroy their eggs.

The eggs show a marked change in coloration during embryonic development. From a bright red there is a gradual change to a clear light brown. As the embyro develops the eyespots become discernable to the naked eye; immediately prior to hatching the eggs are almost colourless. The development of the embryo is, undoubtedly, hastened or retarded by changes in the surrounding medium, warmer currents hastening and colder currents retarding it. Eye-spots have been observed in the eggs of some females of the species *J. verreauxi* in captivity, 30 days after spawning; in others, development to the eye-spot stage occupied 35 days.

The earliest release of the first stage larvae from the egg capsules of captive females was observed 48 days after spawning but the rate of embryonic development is not uniform. In some instances 51 to 55 days pass before the larvae take up their pelagic career.

In the case of females of [*P. cygnus*] eye-spots have been observed in the developing eggs 22 days after spawning, the release of the larvae occurring 38 days after spawning.

Captive "berried females" shield their eggs when moving from place to place. Ordinarily, the forward walking movements are carried out with the pleon extended; during the hatching period it is flexed and rarely extended.

While the "berried female" is otherwise at rest, repeated movements of the fifth pair of legs are noticeable, the dactyls

being employed in the manipulation of the eggs. The pleon is raised and partially extended at intervals, while the uropods are employed in waving or beating motions. The movements on the part of the animal indicate a desire to increase the circulation of the water around the eggs, or to free them from parasitic life or other foreign bodies.

Except in unusual circumstances, practically all the eggs hatch. Dead eggs are dull in appearance. They, with the attached empty egg capsules, are manipulated and removed by the parent female, the dactyls of the fifth pair of legs being again brought into use.

V. LARVAE

"Berried female" marine crayfishes have been held in suitably constructed boxes fed with running sea-water during the hatching period. The first stage (naupliosoma) larvae emerged from the eggs in a cramped condition, the appendages being in a more or less folded position. They floated upwards to the surface of the water and gradually straightened out into the normal position. The space of time occupied appears to vary from about 4 to 5 hours. At this stage the body still contained some of the food yolk and the larvae were not transparent. Rapid beating or swimming movements of the biramous antennae were observed.

Although, to the naked eye, little change is noticeable during the early hours of the life of these minute creatures, various changes have taken place. The food yolk had been used up and exuviation had occurred.

They emerged [from the first moult] in a somewhat advanced (phyllosoma) stage, the swimming setae of the antennae having been thrown off.

Locomotion was brought about by the outer branch of the first two walking limbs which had now assumed the character of a feather-like structure. The body is now transparent and the abdomen has become straightened out into a small rod-like structure composed of four segments. The eyes, on long peduncles, were conspicuous.

The larvae are extremely fragile. Numbers placed in a small vessel in still water soon mass together and die. Attempts to rear the larvae in running sea-water in hatching boxes proved unsuccessful. They gradually died off. On the 11th day but a few remained, and those died soon afterwards. Organic sediment contained in unfiltered sea-water accumulates upon the feather-like appendages of the larvae and it interferes with their swimming movements in the hatching boxes.

In all probability, the food of the larvae is other plankton. No cannibalistic tendencies were observed among the larvae.

Since attempts to rear the larvae were unsuccessful, and since continued observations in the ocean are impracticable, the series of metamorphoses, through which most of their adult characteristics are acquired, cannot be described here. There can, however, be little doubt that these changes, the naupliosoma, phyllosoma, and puerulus, to the calcareous stage, occupy a considerable length of time.

During the month of September in successive years, post-larval *J. verreauxi* have been taken from the surface of the ocean. They were found adhering to, or sheltered beneath, masses of floating algae. They are almost transparent and are not readily discernible when placed in sea-water in a glass vessel. Many of the characteristics of the adult have been acquired. The eyes are

prominent but the peduncles are considerably reduced. The flagellae of the antennae are of greater length than the body. The body length (from the rostral spine to the posterior margin of the tail fan) is approximately 25 mm. Forward swimming movements at, or near, the surface of the water, are brought about by a rapid manipulation of the abdominal appendages. In the performance of retrograde movements the pleon is employed as in the adult.

The behaviour of three of the puerulus taken was observed in a hatching box fed by running sea-water. On the sixth day a change was noticeable in the general appearance of the captives. From that time to the fourteenth day there was a gradual darkening in colour. During the night of that day one moulted; on the night of the nineteenth day, the second moulted. The third died.

In each instance, the newly moulted animal was found at the bottom of the hatching box. It is not known whether moulting occurred there or at, or near, the surface of the water. The newly moulted animals were dark brown in colour. The cast shells were almost colourless; the coloration of the new shells had not been imparted to the old." [These observations on the puerulus of *J. verreauxi* are similar to those of Deshmukh (1966) on the puerulus of *P. polyphagus* (Herbst).]

VI. CONCLUSIONS

F. Aldrich made these observations on captive crayfish at a time when fish hatcheries were in vogue throughout the world. The objective of these hatcheries was to hatch and release larvae of various teleosts and crustacea of commercial importance, in the expectation that better recruitment of juveniles into the fishable stock would result. Aldrich realised the futility of this practice, especially in the case of marine crayfish subject to high mortality during their prolonged planktonic phase. He concluded that "If we can evolve a means whereby the larvae can be fed and reared in enclosures until they have acquired all the characteristics of the adult and are fitted to take up their life on the ocean floor, then artificial propagation will eliminate the dangers to which they are exposed during their pelagic career."

Whether such seeding of coastal reefs with post-larval juveniles would succeed in increasing recruitment to the fishable stock is another question. F. Aldrich appreciated the necessity for detailed studies of the life history and ecology of these species so that we can properly evaluate the prospects for any form of artificial propagation.

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